Failure Analysis & Prevention
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Lecture – 37
General Procedure of Failure Analysis: Reporting Failure Analysis and Failure Analysis of Welded Joint

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention. And we are in very last part of the general procedure of the failure analysis, and today first of all we will be talking about the method of reporting of failure analysis and thereafter we will take up the failure analysis of the welded joints.

So, we know that the failure analysis is a very time consuming, every exhaustive and very effort taking activity, which involves lot of testing in directions with the people characterization of the material and thereafter formulating the conclusions. So, what a report should include?

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Basically the report should be written very clearly in terms of the kind of the results which have been obtained, and the way by will and with the justification why the these have been considered as a potential causes of the failure and then it should be concise also it should be to the point and then it should be logical. Logical means the things are

should be written in such a way that there is a proper linkage of the information given at point one to the subsequent stages.

So, and that is why, what we say that first of all we mention the design aspect so, then and the kind of a the service conditions, then manufacturing of the product and thereafter it is the general information about the failed components, the destructive testing, non destructive testing, macroscopy microscopy. So, all these will have the linkage with each other and the they need to be and they will be sequential.

So, but all the cases may not involve all the steps of the general procedure of the failure analysis. So, as per the case we have to identify, what with the different headings under which the report should be prepared. So, the this is the general thing that report should be clear concise and logical one, but they are certain points which have which are generally included in the failure analysis of the metallic components.

So, this includes like the description of the component which has failed.

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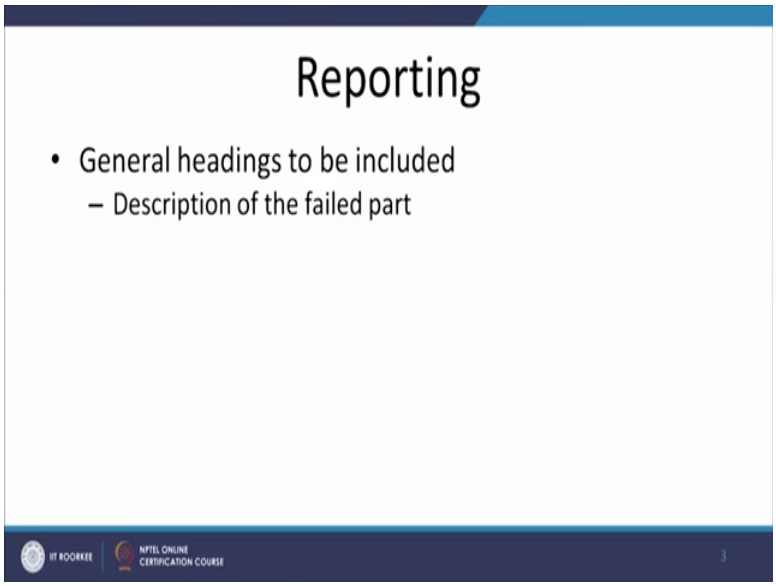

So, this description basically will involve the details about the components which has failed like, which what was the name of the component what was the and where this part was fitted in for, how long this has been in service under, what conditions it has been serviced and what was the condition after the failure. So the description of the failed

component like the name, assembly, the part number, and the service conditions which have been experienced for how long it has worked under those service conditions.

So, the next is the service conditions at the time of failure. So, at the time of failure what were the service conditions? So, the general service conditions are one thing that the time the service conditions like the load, the temperature, the environmental conditions and these need and etcetera this need to be identified exactly what was what were the service conditions at the time of failure.

Then we have to mention the manufacturing process conditions which have been used for making the component. So, manufacturing and processing history of the failed component is detailed out like what was the kind of the dimensions of the different parts, how they were made, what were the different steps forming in the component whether and how it was heat treated if at all it was subjected to the heat treatment, how it was finished. So, all those come details are mentioned.

So, description on the then the service after the description we need to mention the service conditions at the time of failure, then the manufacturing and the processing methodology used for making the component and then we have the data which has been collected about the mechanical properties of the material.

And thereafter we need to see the metallurgical in mechanical properties we know that all the tensile properties, hardness, toughness, fatigue creep as per the case the data will be collected and the information will be mentioned here then the metallurgical evaluation of the failed component, which basically involves the microstructural part like the green size, shape, the phases which were present the inclusions porosity etcetera then chemical analysis of the component, which has failed and thereafter summary of the mechanisms of the on that have summary of the mechanisms which have contributed towards the failure of the component.

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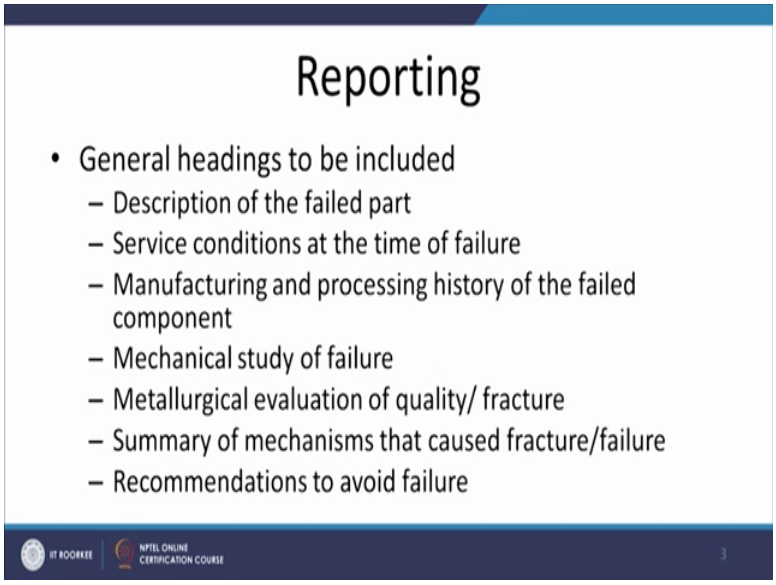

And the lastly we need to mention the recommendations so, that the reoccurrence of the similar kind of the failure can be avoided. Under this basically and the recommendations are made in light of the potential causes of the failure. For example, the for if the wear is taking place due to the limited or the low hardness values then will be ensuring that in case of the steel carbon content is increased or the heat treatment is carried out under the process, proper conditions or the surface treatments are special surface treatments are carried out so, that required hardness is maintained.

So, as per the case of the failure suitable kind of the recommendations are made so, that the similar kind of the failures can be avoided. In addition to this these are the points which are very general in nature as per the case that we may have to have the different kind of the points, to in order to detail out the failure analysis of a particular product.

So, as per the case the different sections may be designed and accordingly report can be prepared another important thing lengthy reports will have obstruct and executive summary, because failure analysis report sometimes run in length of like say 100 of the pages. So, it is difficult to make out anything after and if we have to understand it properly, then someone will have to go through all 100 of the pages so, that one can understand.

So, in order to make it easier instead of going into all the technical details related with the report a an executive summary is prepared especially in case of the extended the failure analysis of the complicated products, but if the report is limited in few pages then

probably the abstract or the executive summary is not needed. So, length in case of the lengthy reports, say that executive summary or the abstract is prepared. So, one can easily understand what were the important factors, which have played a major role in the failure of the component. It would be good to prepare the glossary of the drums used in the report so, that the reader can really understand the various aspects which have been mentioned in the report.

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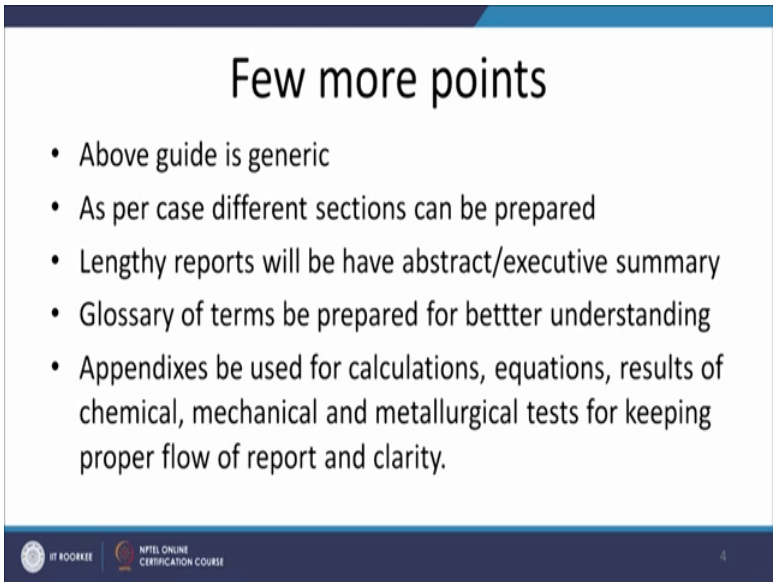

Additionally it is also important to the to mention some of the details as appendix is details like we will be having lot of the data about the mechanical and metallurgical properties and the service conditions under which failure has taken place, there may be lot of calculations also use of equations. So, what is done normally that calculations increases results of the chemical and says mechanical properties and metallurgical test all are kept as appendix. So, that the content of the report the there is a proper flow in the content of the report and one can easily understand various aspects related with the failure.

So, these were some of the points related with the preparation of the report of the failure analysis. Now, we will be talking about the general procedure of the failure analysis especially for the welded joints. We know that the weld joints are weld joints are can be made using various methods, which involve like the fusion of the components to be joined or it can simply involves the plastic deformation or it can also involve a just then

the putting the low melting point metal between the components to be joined. So, as per the case and we need to see a in the way by which the failure analysis need to be carried out.

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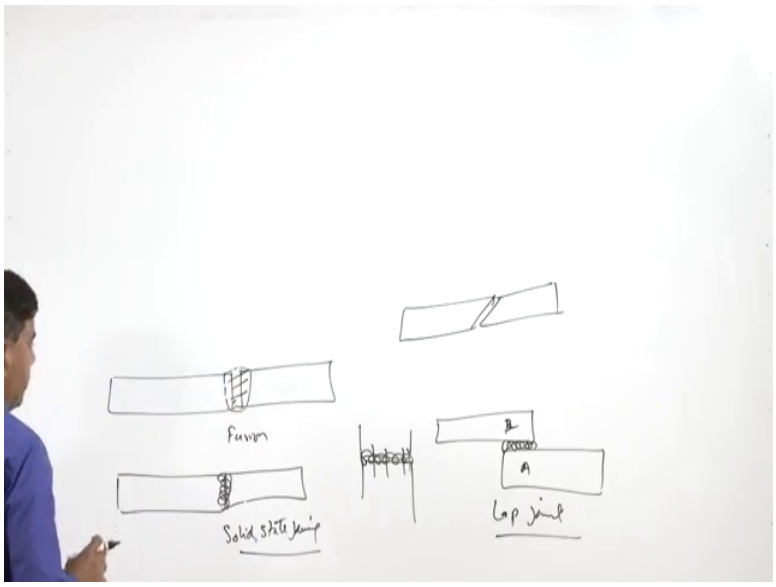

So, there can be the three different cases like in one case where we are fusing the edges of the plates to be joint. So, this is this basically involves the fusion.

In the second case we do not fuse we just put the things together in butting position and forcefully, the plastic deformation is facilitated to move the material from one side to another and this happens in case of the solid stage joining. Sometimes we just put the components in butting position in under the firm contact conditions under pressure at the temperature. So, that diffusion across the interface takes place. So, not just larger scale plastic deformation, but macro scale deformation at the interface also helps to have the joint.

Now, since the since these joints are made using the different approaches in one more case. So, this is a solid state joining there is one more case where just the component to be joined are just heated is heated to the high temperature so, but is still there will remain in solid state and in between we put the low melting point metal, which we will be forming the connection between the two. This is especially we used when the two components have the metallurgical incompatibility and it is required to make the joint which is really weaker. So, normally for this purpose the lap joint is; lap joint is used;

however, the butt joints are also used by making some modification to increase the surface area of the joint like this so that the butt joints can also be made.

The point is like since the different approaches are involved. So, the causes will also very significantly and we will be taking up the case. So, one of the most commonly used category of the joining process is the fusion one; wherein when we apply the heat for melting the failed surfaces of the components to be joined.

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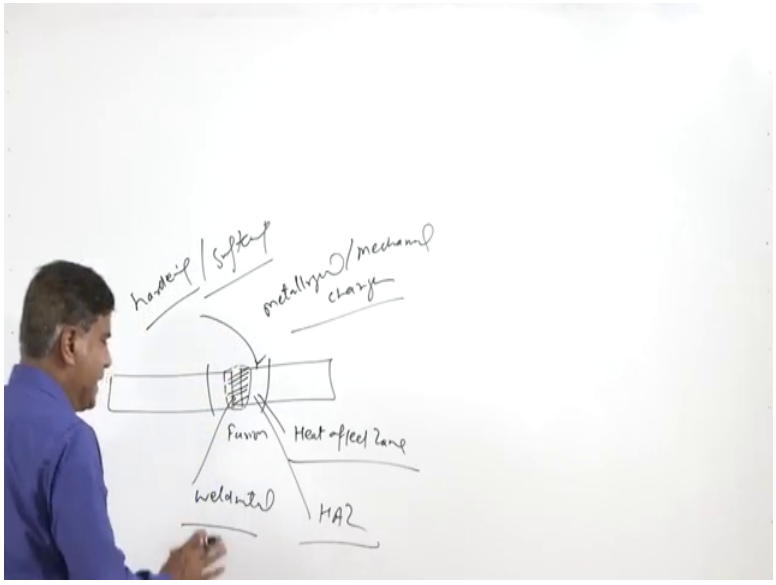

The it develops the pool of the molten metal, which after the solidification results in the metallurgical continuity, but apart from that there is a formation of the zone which is affected by the heat this is called heat affected zone.

So, the in this zone basically both metallurgical as well as mechanical changes or mechanical metallurgical and mechanical changes are observed. So, if because of these mechanical and metallurgical changes, sometimes it is the hard and the stronger than the weld joint and base metal and sometimes it is weaker. So, in both the cases there can be both the possibilities where hardening or of the softening of the heat affected zone is taking place and many times this becomes as a source of the failure.

So, the there can be two aspects to be seen with regard to the failure analysis. So, technical failure of the weld joints one is the issues related with the weld metal or the issues related with the heat affected zone, and this need to be seen separately there are

different kind of the problems which are experienced by the two zones. As far as the technological problems the failure is concerned, technological problems related with the failure of the weld joints is concerned.

So, now we will see the different aspects related to the failures related with the failures of the weld joints. You know the failure of the weld joint is encountered in the two stages one is when the failure is observed at the fabrication stage. So, like we are developing the weld between the two components and suddenly we find that no it has got cracked after sometimes.

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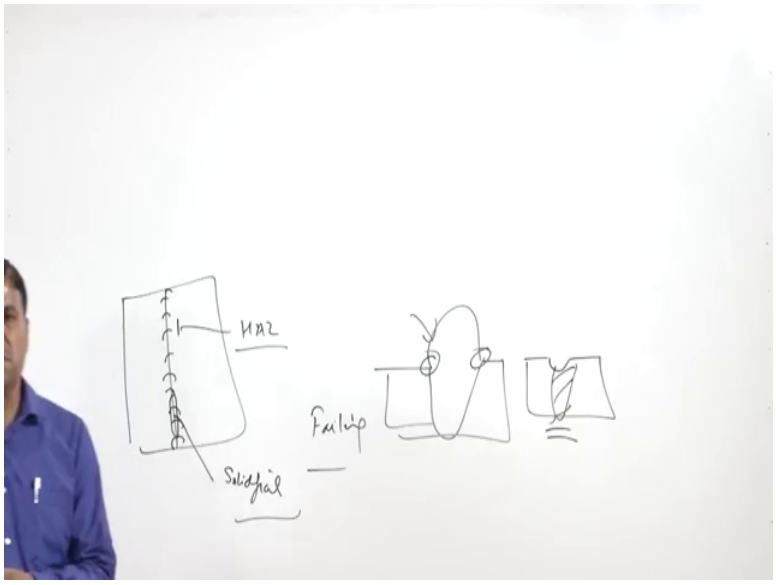

So, as soon as you complete the weld, you find that one crack is running all along the weld or in the heat affected zone.

So, this typical one is called a solidification crack or there may be at HAZ crack due to the cold cracking or something some other reason. So, this one cracking one type of cracking where the joint made is a failing due to the and due to the it can fail due to the number of aspects like the weld with geometry is not proper it is very rough or the weld bead is too convex like this or weld bead is to concave like this.

So, there can be various aspects, which can lead to the failure of the weld made. So, this is very convex and this is concave weld bead leading to the reduction in cross sectional

area this is causing too high stress concentration at the part, at the two of the weld and which will be easily triggering the crack nucleation and there failure.

Then on thermal metallurgical changes, unnecessary dissolution of the gases florestein inclusions and lack of melting; So, there can be various sources and causes of the failure and if a such kind of the failures occur during the fabrication stage, which of course, will be detected through the inspection and testing of the material, and if it fails then we need to take certain corrective actions so that, the some weld can be prepared.

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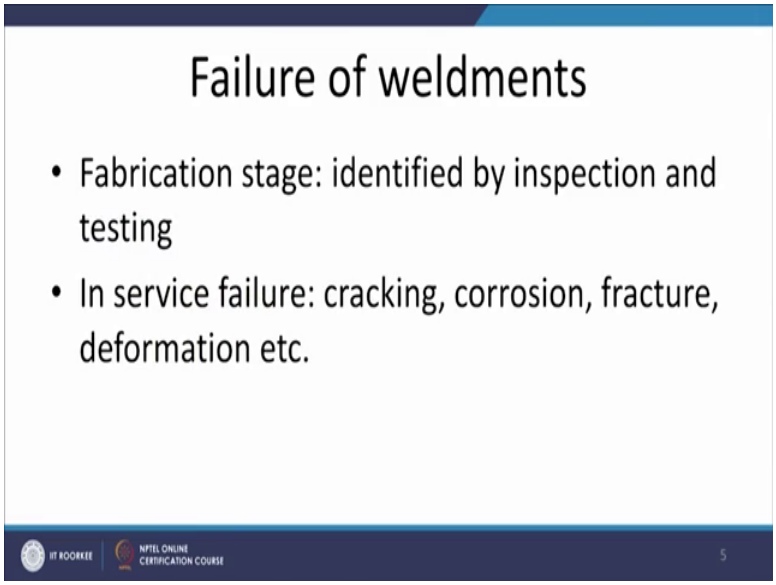

There is another category of the failures with regarding which we are more concerned that is with the failure of the weld joints and during the service. So, basically failure analysis subject is for those failures, which occur due to the conditions experienced by the product during the service.

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So, basically service failures of the weld joints occur can occur in various forms and the common ones are like one is the fracture especially the fracture of when fracture occurs due to the high stress concentration at the two of the weld; stress concentration at the two of the weld or weld is not able to take the load, loading capacity is reduced loading capacity is less.

There can be deformation of the weld there can be corrosion of the corrosion is leading to the reduction in dimensions and so, the corrosion, cracking, fracture, deformation these are the bigger the ways by which failure of the weld metal can occur during the service. Now, the failures of the weld which are triggered by the various types of the discontinuities in the weld joints and.

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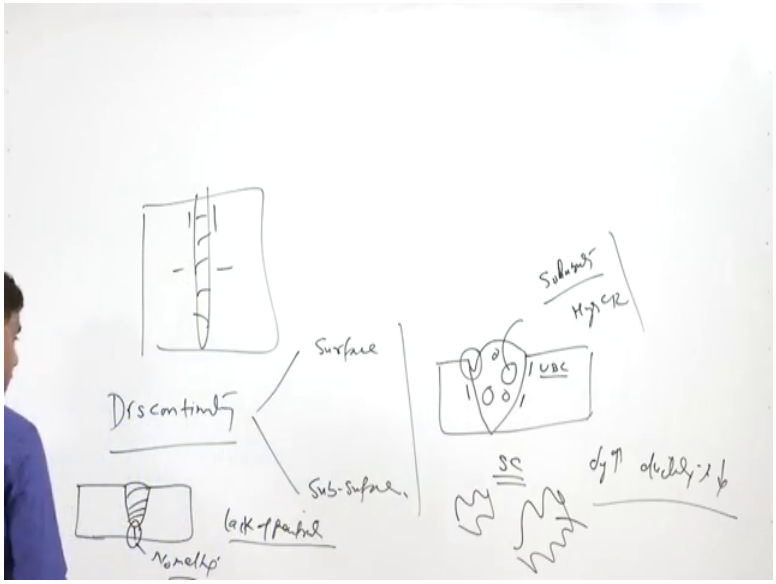

So, there are two types of the discontinuities we know that the weld joints are invariably have the discontinuities or this discontinuities may be from very fine to the very course one. So, if they are course one of course, the weld joint is rejected, but if they are fine when within the acceptable limit, then the weld joints is used in the service.

So, there are two category of the discontinuities, which are normally observed these discontinuities are in invariably present at the weld joints and they facilitate the failure of the weld joints. So, the surface discontinuities and the subsurface discontinuities and so, what we can see that, surface discontinuity one is the mismatch.

So, these are the discontinuities which can be seen at the time of fabrication on itself. The poor weld meet geometry where excessive, concavity, convexity or very irregular or rough bead is present at the surface.

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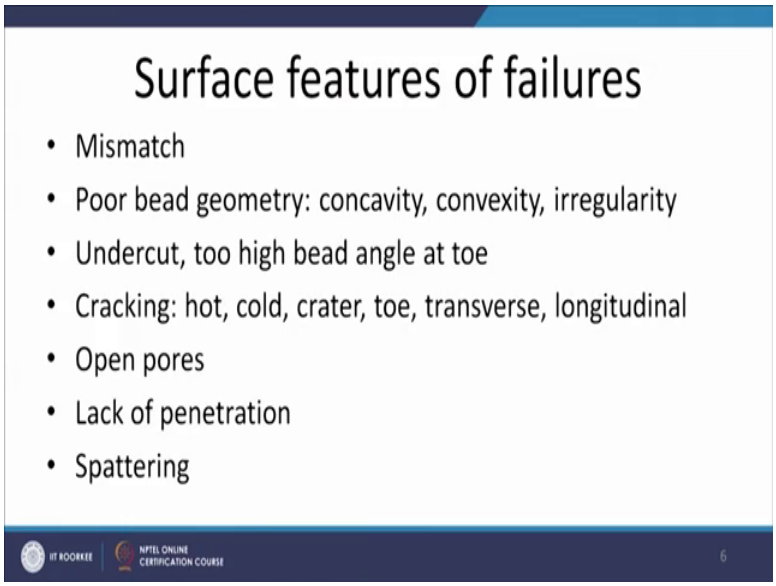

Then there is a undercut which is or very high bead angle is there we know that undercut is found in the situation like this, this is the weld bead and the weld is prepared like this. So, this one where either excessive heat input, it means excessive welding current or excessive high speed of the welding arc is used then it leads to the undercut.

This itself acts as a stress concentrate under the stress which are easily facilities the crack nucleation and its grown especially, when the material yield strength is high and the percentage elongation in terms of the and ductility, in terms of the percentage elongation is very limited for high hardness, high yield strength and low ductility metals they easily are facilitate the nucleation and grown of crack.

Then there can be various types of the cracks like hot crack, which occurs in form of solidification cracking cold crack like the neat cracking or hydrogen induced cracking then a cracked cracks are occurred at the location where the weld ends.

Because of the high concentration of the aligned elements the cracking occurs near the crater, in the crater of the weld then the toe the cracking occurs at the toe of the weld due to the high stress concentration, then as per the orientation of the cracks there can be transverse cracks or longitudinal cracks, the transverse cracks will be running perpendicular to the direction of the welding, while the longitudinal cracks like this is the welding direction.

So, the transverse cracks will be like this and longitudinal cracks will be running all along the weld, then there will be open course when the two high misses under the turbulent conditions of the molten metal, come of the open pores can be formed at the surface of the weld. Then there can be lack of penetration, which we can easily see from the by looking the weld from the bottom side, what we can see here the weld at the top is seems to be perfect, but in the lower side there is no melting.

So, this indicates the lack of penetration, where through thickness penetration is missing. Then sputtering lot of the molten metal will be falling here and there which will be promoting the which will because whenever sputtering happens it will be leading to the increased roughness at the surface and sometimes hard spot formation, especially in the hardnable steels leads to the in inflation and growth of crack to facilitate the failure of the components. Then there are few subsurface features which also promote the failures like the underbead cracks.

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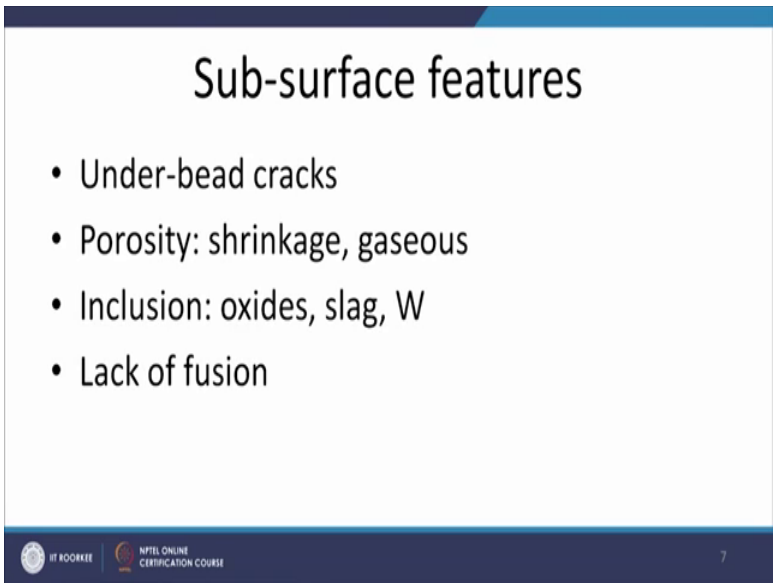

Porosity in form of like the shrinkage porosity or the gaseous porosity, it is easy to a identify the underbead cracks these are normally obtained just below in the heat these are these are found in the heat affected zone next to the fusion boundary, these are called underbead cracks and then there is a shrinkage porosity and the gaseous porosity.

Gaseous porosity mostly due to the high difference in the liquid and solid state solubility of the gases in the molten metal, and the high cooling rates; So, these are the two regions

one is the solubility and another is the high cooling rate and these two conditions lead to the interactment of the gas troubles in the weld metal these are always spherical family and that is why these are called gaseous defects in form of the porosity.

While the shrinkage porosity happens due to the lack of feeding of the molten metal and which will be in form of the like the this the surface of the pores will be of the dendritic in nature and it will be not be of a spherical family. So, such kind of the defects porosity is called the shrinkage porosity and primarily happens due to the limited feeding of the molten metal, limited flowability of the molten metal, to fill up the gaps between the dendrites, which are growing during the solidification of the weld metal.

Then the oxide inclusion, slag inclusions and tungsten inclusions, tungsten inclusions typically is found in case of the tunga tig or the tungsten in order gas welding also termed as GTAW and copper inclusions are found in case of the GMAW where the mig process where the copper nozzles are used sometimes copper particles. So, get detached and they get transferred into the weld pool and oxide inclusions are common in various processes, especially where the inert gas is not used for protecting the weld metal or where vacuum is not used like an electron beam.

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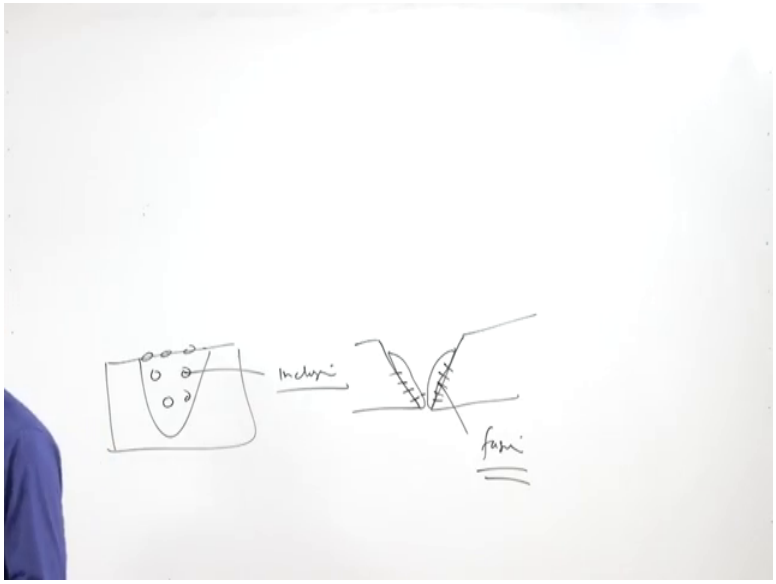

So, the reaction of the molten metal with the atmospheric gases forms the oxide layer, and if the oxide layer is having the similar density as that of a metal, then it starts to set and to get uniformly distributed in the weld metal and that will be present in form of the

inclusions. These inclusions act as a discontinuities in the weld metal and then the lack of fusion where, the during the like this is the prepared surface of the these are the prepared surface of the plates to be welded and due to the limited heat input if the welding current is very less, and heat generation will be limited and that may not able may not be able to melt the base metal, in that cases molten metal will be will be placed over the surface of the base metal.

So, lack of the melting of the base metal and fusion with the weld metal will be reducing the strength and these zones will be there as a lack of fusion and which will be providing the easy source of the fracture. Now, the there are some general factors which ca general causes, which lead to the various types of the defects.

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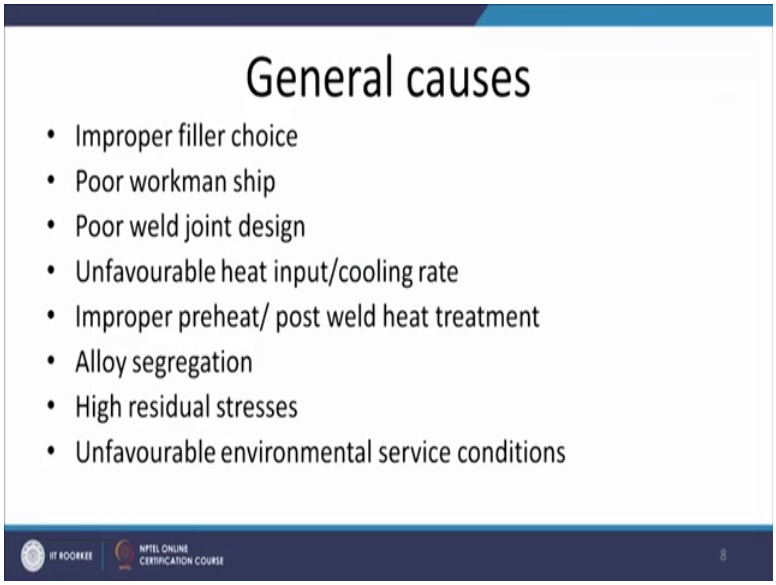

These are very generic in nature these problems may be caused. So, the different problems have been grouped as a general causes of the failure, wherein what we can see improper filler choice improper poor workmanship and poor weld joint design unfavorable heat input and so, the unfavorable cooling rate, improper preheating like too low or too high preheat is used. Similarly the post weld heat treatment if not proper alloy segregation high residual stresses and unfavorable environmental conditions.

So, if any of these causes over there then these need to be identified and for this purpose we need to see the we need to do the macrosocpy of the weld joints, we need to do the design analysis of the weld joints which have failed, we need to also see go through the

details which have been used for details of the welding procedures, which have been used for developing the weld joints like and the kind of the process, process parameters, filler, the post weld heat treatment and the preheating and also if there is a possibility of the residual stress development that also needs to be established. Then we will be talking about the general steps first of all which are used in the failure analysis of the weld joints.

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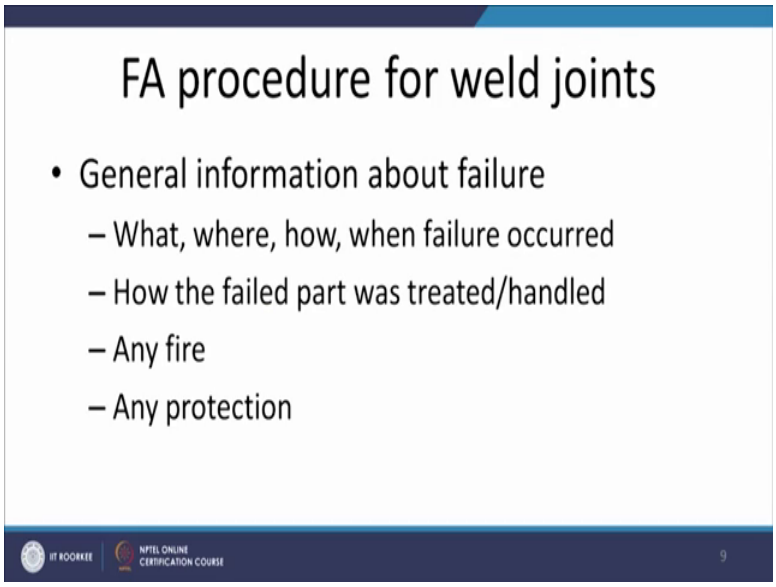

So, these are these will be diff slightly different than what we have talked about the general procedure of the failure analysis of any component, here we will be talking especially with reference to the weld joints.

So, what we need to mention or determine first we need to identify what has failed, where that failure of the weld joint has taken place and how the failure has been caused and when that failure has occurred. And if the failure has occurred then how the failed part has been handled or treated was there any fire or was there any protection while handling the failed component.

Thereafter, we have to talk about under what conditions weld joint has worked during the service in terms of the loading.

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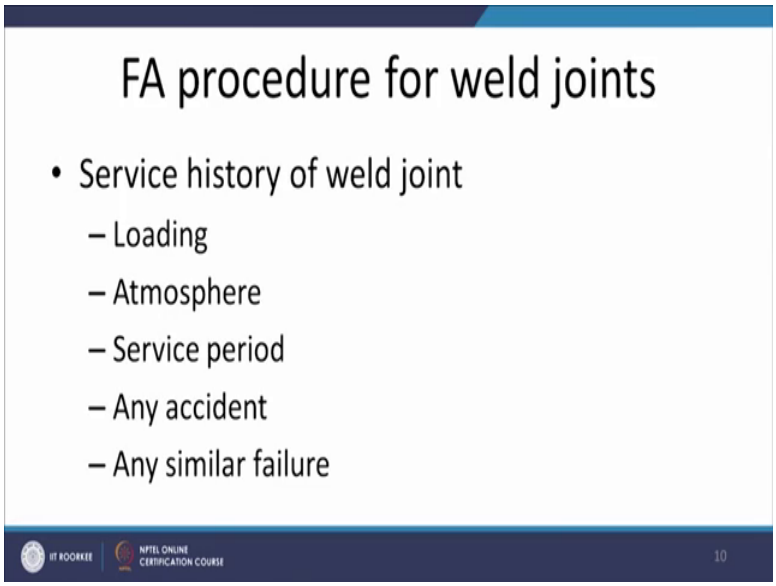

For the loading we need to see the type of the loading with regarding to the static or the dynamic loading, impact loading or the cyclic loading, then the type of a the load which was there whether it is tensile load shear load or the bending one, then the atmospheric conditions under which component, component has worked whether it was a whether it was the corrosive or the normal ambient condition, whether it was a high temperature or low temperature or any specific environment like the liquid molten metal or any other like alkaline or the halite environment, in which the joint has worked then how long the weld joint has worked under those conditions.

If there was any accident or any similar kind of the failure has been reported earlier for such kind of the weld joints.

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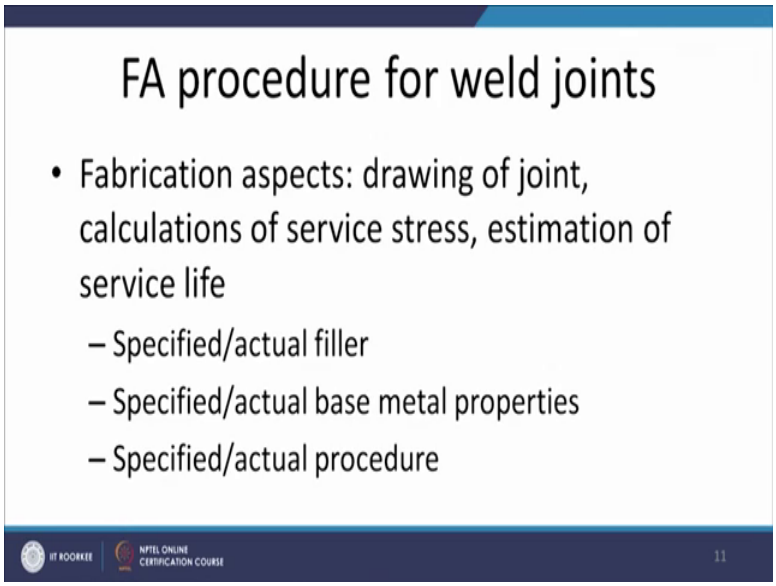

Thereafter, we need to see the fabrication aspects in which the design aspects related with the weld joint and for that what we need to step identify or establish that, I we need to find out the drawings of the joints and we need to check the calculations of the surveys stresses and also if there was a fatigue loading, then we need to based on the service conditions we need to estimate the expected service life. And also there are three other aspects which can be seen with regard to this, what was the specified and actually used filler.

So, for this, this can be simply specified through the drawings we can identify what was the specified filler and through the chemical analysis we will be able to identify what was actually used. Also this can be this information can be obtained through the questioning the welders which over there or the kind of the actual the welding procedures used for fabrication of the component.

Similarly, the what was what were the specified the base metal properties and what were the actual base metal properties, then what was the actually procedure of the welding and what was the specified ones. So, information about these is collected.

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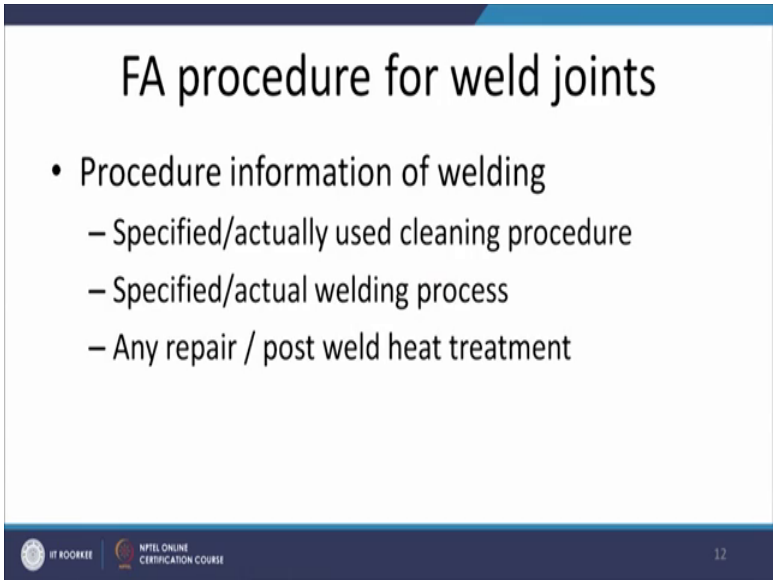

Then we need to especially specific in a we need to collect the information and with this a specific through the welding like what was the actually used cleaning procedure of the flying surfaces or what was the specified. Whether was then like there can be difference with regard to the if just mechanical cleaning was recommended and instead of using mechanical cleaning, if some chemicals were used which charged the hydrogen in the base metal and they induce the cracking by the hydrogen and this cracking.

Similarly, what was the actual welding process and what was the specified one. And if was there any repair of the weld joints or was there any post weld heat treatment.

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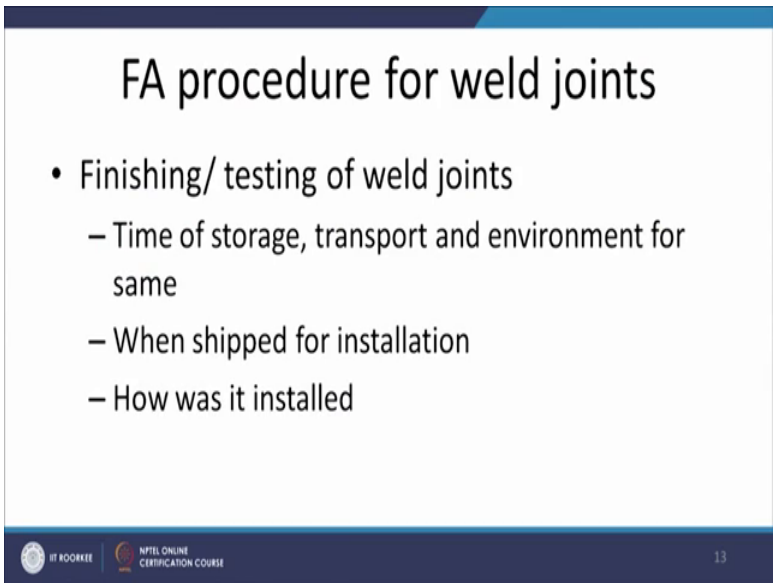

So, this information is collected and thereafter we need to also find out the information about the finishing and testing of the weld joints is after the finishing of the weld joints, how long the weld point was kept in a storage how long it was transported and under what conditions if it was stored and transported, thereafter when it was shift for installation and how it was installed.

So, these information they will be collected just to familiarize with the conditions thereafter, we will be starting with the testing and analysis procedures for the weld joints, which will basically involve macroscopy, microscopy chemical analysis chemical analysis, mechanical properties, studies metallurgical properties studies or the weld joint and thereafter after the analysis after characterizing the field weld joints will be integrating all that information to identify the primary few primary and potential causes of the failure.

So, about the examination procedure of the weld joints, we will be talking in the next presentation. Now, we will surprise this presentation in this presentation basically I have talked about the methodology for preparing the report of the failure analysis and thereafter I have talked about what general things we need to collect, and what information we need to collect for the failure analysis of the weld joint. Detailed procedure of the failure analysis of the weld joint we will be talking of in the next presentation.

Thank you for your attention.